AIMS Energy, 8(1): 102–121.
DOI: 10.3934/energy.2020.1.102
Received: 06 September 2019
Accepted: 04 December 2019
Published: 05 February 2020

http://www.aimspress.com/journal/energy

Review

Utilization of *Moringa oleifera* oil for biodiesel production: A systematic review

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Abstract: A major energy challenge currently is the depletion of global oil reserves which is gradually resulting in the decline of conventional diesel production. Several alternative fuels and renewable energy sources have been proffered with biodiesel constituting a promising option. Biodiesel has garnered increasing attention because it is renewable, biodegradable, non-toxic, and it is characterized by low carbon monoxide particulate and hydrocarbon emissions compared to the conventional diesel. In recent times, several scientific writings have documented the utilization of *Moringa oleifera* as feed stock for biodiesel production. *Moringa oleifera* (horseradish) is a multipurpose tree species and one of the most widely cultivated crops in tropical and sub-tropical areas of the globe. Databases used for this review include Google Scholar, Scopus, WorldCat.org, Microsoft Academic and Science Direct. A total of 216 articles were retrieved and 18 studies were ultimately retained after qualitative analysis. The analytic output shows the seed oil has favorable characteristics for use as biodiesel. The fatty acid composition of the oil makes it suitable for both edible and non-edible applications. Also, the percentage of oleic acid (70%) in Moringa oil is quite high compared to other crops which possess about 40% oleic acid. Moringa seed oil exhibit a high oxidative stability and its thermal stability exceeds other oil crops like sunflower oil, soybean oil amongst others. Biodiesel produced from *M. oleifera* seed oil exhibit enhanced oxidative ability, high cloud point and a higher cetane number of approximately 67 than for most biodiesels. *Moringa oleifera* biodiesel can be stored for a long period of time and it is safe for transport.

Keywords: *Moringa oleifera*; biodiesel; biofuel; alternative fuel; renewable energy

1. Introduction

The geometric rise in world population has resulted in a subsequent increase in the demand for energy which can lead to insufficient energy supply [1]. The effect of insufficient energy can be detrimental to the global economy which is dependent on energy [2]. Fossil fuel has been a major source of energy production for some years now [3]. However, fossil fuels are non-renewable energy sources and thus limited in supply. It also poses a lot of health and environmental problems. These energy resources are not evenly distributed around the world; it is more concentrated in some countries than others. Therefore, countries not having these resources are forced to import crude oil, thereby encountering challenges accompanied by importation such as foreign exchange crisis. These countries will seek for alternative fuels that can easily be produced from indigenous materials available within their country [4].

Depletion in fossil fuel resources has led to the search for alternative fuels and also renewable energy resources [5]. Klass model for fossil fuel depletion predicts that crude oil resource will last for the next 35 year. This prediction is worrisome for world economic development and sustainability. However, this predictions like other predictions are not absolutely certain [6]. In addition, the indiscriminate mining and consumption of fossil fuels have contributed to the reduction in petroleum reserves [4].

The natural and renewable domestic fuel generally termed biofuel is considered as a promising and economical alternative and likewise a sustainable energy source [7–9]. Biofuel is a fuel produced from any renewable biomass material. It is commonly used as an alternative, cleaner fuel source to burning fossil fuels [10]. Biofuel can be produced from various materials which are in contrast with conventional diesel that can be produced from only a specific type of material [11]. Liquid biofuel is a type of biofuel which is essentially employed in fuelling vehicles and sometimes engines [12]. Biodiesel is a liquid biofuel produced through the process of transesterification which converts fat and oil into fatty acid alkyl ester and a co-product glycerol in the presence of an alcohol (methanol and ethanol; Figure 1) and the appropriate catalyst [12]. The raw materials for biodiesel production include vegetable oils (edible or non-edible), yellow grease, used cooking oils, or animal fats. These fuel sources are said to reduce engine wear and produce less harmful emissions [13]. Biodiesel sources should be of low production cost and have large-scale production. Certain factors that can influence the quality of biodiesel fuel include the type of raw feedstock used, the production process, and upstream production processes. Fuel quality issues are usually reflected in the contaminants or other minor components of biodiesel [14].

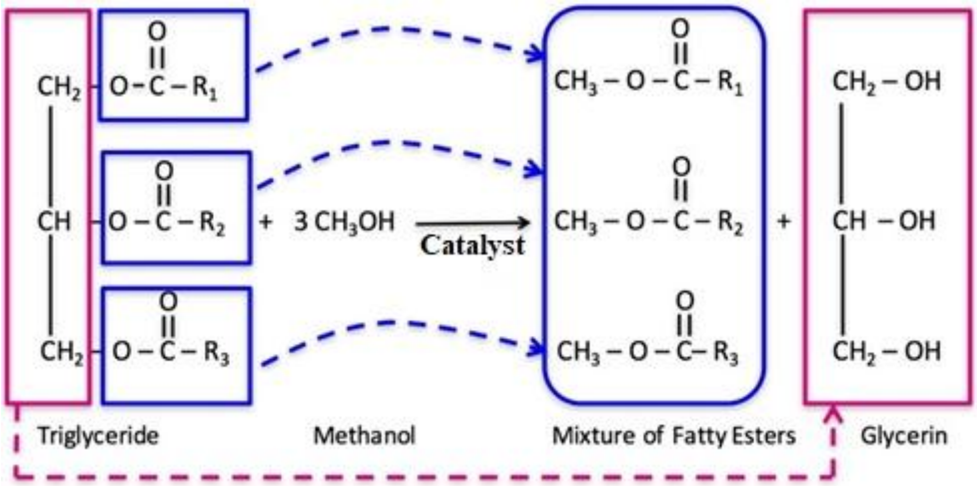

Figure 1. The transesterification reaction of triglyceride with methanol in the presence of catalyst to produce biodiesel (fatty acid methyl ester) and glycerol [15].

Biodiesel made from vegetable oil has been reported to burn clearly, which significantly reduce pollutants contributing to smog and global warming [16]. It is predicted that biodiesel will reduce dependence on fossil fuel and oil reserves [17]. Biodiesel is renewable, biodegradable and non-toxic compared to conventional diesel [1]. Interestingly, Biodiesel can be used in its pure forms or as blends with diesel fuels without engine modification but ensures better performance [18].

Vegetable oils used for biodiesel production differ significantly with location according to its availability. The common feedstock for biodiesel production includes rapeseed oil, sunflower oil, palm oil, canola, soybean oil and animal fats [14]. The type of feedstock used influences the quantity of biodiesel produced. This may be due to the physico-chemical properties of the feedstock used [19]. In recent years, *Moringa oleifera* seed oil has been shown to be a promising feedstock for biodiesel production [12]. *Moringa oleifera* belongs to the family Moringaceae. It is native to Himilaya in northern India and Pakistan. It has also been introduced in Afghanistan, Southeast Asia, East and West Africa, Southern Florida, the West Indies, Mexico, Peru, Paraguay and Brazil. *M. oleifera*, among the other species, is the most extensively cultivated and studied [20]. It is an evergreen, fast-growing and deciduous plant. It requires rainfall about 250-2000 mm depending on soil condition. It grows best in dry sandy soil and tolerates poor soil with pH range 5 to 9 [21]. Every part of *M. oleifera* tree is beneficial and can be used as food, medicine, coagulants, animal fodder, fuel, fertilizer, honey, cleaning agent, gum, water purification and manure [20]. It has been cultivated in tropical regions all over the world due to its high protein, vitamins, mineral and carbohydrate content, high nutritional value for human and livestock and its medicinal uses [22]. The seeds contain about 42% oil content which is highly flavored and edible [23]. The oil is light yellow in color and has a characteristic sweet nutty flavor. The fatty acid composition of *M. oleifera* oil makes it suitable for both edible and non-edible applications. The percentage of Oleic acid in Moringa oil is high, roughly 70% and may be the reason behind its ability to increase beneficial HDL cholesterol and decrease the serum cholesterol and triglycerides. Furthermore, Moringa oil is highly resilient to oxidation, and can therefore be employed as an antioxidant for stabilizing commercial edible oils for a long period of time. Also, its thermal stability exceeds that of soybean, sunflower, canola and cottonseed oils. Besides the use of Moringa oil for biodiesel production, it has other uses which have been explored in cosmetics, folk medicines and skin care formulations [24,25].

The international interest in Moringa is increasing due to the fact that it can produce about 3000 kg of seeds from 1 hectare, from which 2000 liter of biodiesel can also be produced [17,24]. Interest also lies in the fact that Moringa is readily available, indigenous and also economical [26]. Similarly, all parts of Moringa are edible and biodegradable unlike Jatropha which produces a toxic nuclear waste after oil extraction [27]. Moringa can grow on poor soils and under drought conditions, thus its production will not be affected by environmental conditions. This ensures sustainable production of *Moringa oleifera* oil and subsequently biodiesel from the oil [27]. However, Moringa oil is not regarded as an edible oil in Nigeria; thus, extraction of oil for biodiesel production will not affect availability of food which is the major subject in the debate against the use of vegetable oil for biodiesel production [13,26]. Biodiesel produced from *M. oleifera* seed oil exhibit enhanced oxidative ability, high cloud point and a higher cetane number of approximately 67 which is higher than most biodiesels [17]. Nadeem and Imran [24] also reports that the recovery of biodiesel from Moringa oleifera seed oil is high as against other crops. Therefore publicly available literature on *Moringa oleifera* have been systematically reviewed to provide information on the production of biodiesel from *Moringa oleifera* and its engine performance. This review focused on the various methods employed in biodiesel production from *Moringa oleifera* seed oil and also examines the quality of the biodiesel fuel if it meets standard requirements of biodiesel as well as the stability of the seed oil and its uses in combustion engines.

2. Methods

2.1. Criteria approach

Studies on biodiesel production from *M. oleifera* seed oil were broadly searched.

Inclusion Criteria: Studies were included in this review if it reported methodology of biodiesel production, quality and efficiency of biodiesel from *M. oleifera* seed oil.

Exclusion Criteria: Studies were excluded if the literature reported biodiesel production from other sources, the literature was incomplete and not written in English.

2.2. Case definition

According to Romano and Sorichetti [28], biodiesel is a liquid biofuel produced through the process of trans-esterification which converts fat and oil into fatty acid alkyl ester and a co-product glycerol in the presence of an alcohol (methanol and ethanol) and the appropriate catalyst.

2.3. Quality assessment

The full texts of each studies were accessed to ensure that biodiesel explicitly depicts the above case definition. Errors in study design and execution were screened and literature affected were excluded from the study. The study materials and methodologies were carefully examined to see if it was clearly explained and carried out according to standard operations.

2.4. Data extraction

The search and selection of studies were carried out separately by three reviewers (OEE, AAA and EEC). Any disagreement between the three reviewers over studies selection was sorted through a re-assessment by a fourth reviewer (OAC). Relevant information from all the included studies for the research was extracted, compiled and saved in an excel spreadsheet. Extracted data were based on the Author, country, year, methods used in biodiesel extraction, alcohol and catalyst used. In addition, information about the engine performance and emission production were also extracted.

3. Results

3.1. Systematic search

The search extracted a total of 216 literatures from Scopus, Science Direct and Google Scholar recording 62, 106, and 29 respectively. Additionally, 19 articles were hand-searched from reference lists of selected studies. Other articles were extracted from WorldCat.org and Microsoft Academic databases. The results were sent to Mendeley 1.19.2. 39 duplicates were eliminated. A total of 177 articles were screened for relevance to the subject matter, with 148 study excluded. Of the remaining 29 articles, 11 were excluded for assessment as full papers. A total of 18 articles were included for data extraction and quality appraisal (Figure 2).

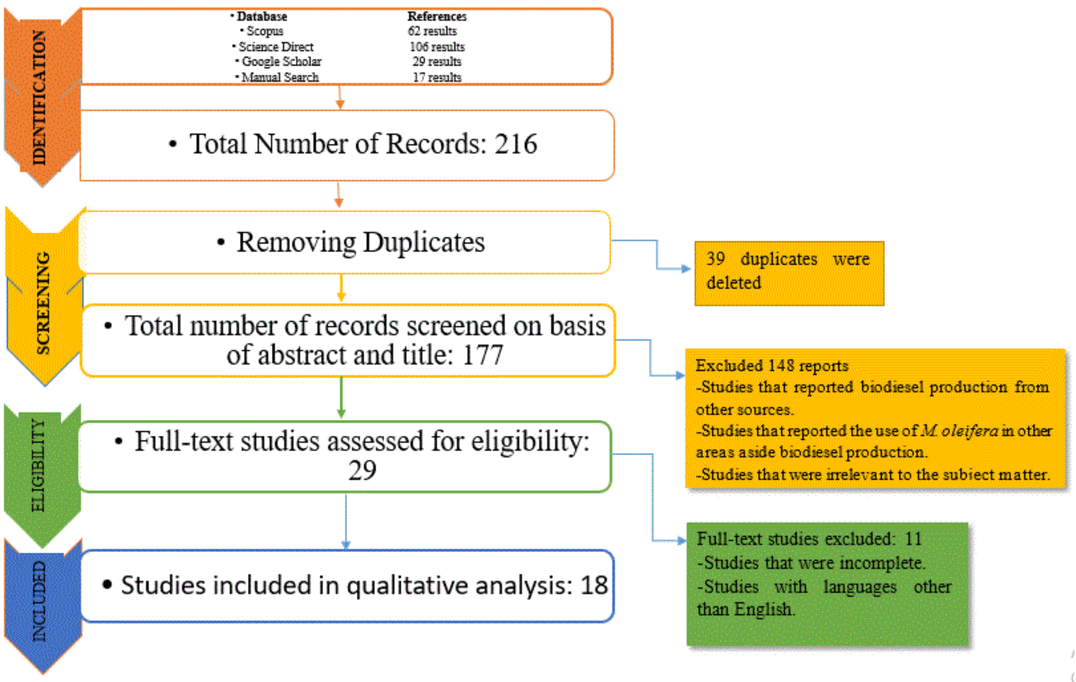

Figure 2. Flowchart for the selection and screening of articles used for the study.

3.2. Study characteristics

This review has 21 studies conducted in 9 countries of the world. 6 studies were extracted from Malaysia, 3 from Brazil, 2 each from Pakistan, India, Iran and South Africa, 1 each from Nigeria, Australia and Thailand. All included studies were conducted between 2000 and 2019, covering a period of 18 years. Details of the study characteristics are summarized in Table 1.

Table 1. Characteristics of included studies on biodiesel from *Moringa oleifera* (MO).

Reference	Country	Specific objective	Mob production	Findings	Engine performance
[17]	Pakistan	Utilization of MOME as a possible source of biodiesel.	Transesterification reaction of 6:1 molar ratio (methanol:MOO) for 1 h at 60 ℃ with 1% $NaOCH_3$ catalyst was carried out.	The oxidative stability of MOB is improved compared to other biodiesel fuels, although it has a high cloud point.	_
[29]	South Africa	Optimum production parameters for the production of MOB using alkaline catalyst.	The catalyst concentration was varied from 0.5% to 1.5% of oil; the methanol to oil ratio was varied from 10 to 50% of oil; the reaction time was varied from 30 min to 90 min; the temperature was varied from 30 ℃ to 60 ℃.	Larger catalyst amounts favored the saponification process while greater amounts of methanol hinder the separation of glycerin from the biodiesel.	_
[16]	South Africa	The use of heterogeneous catalyst for biodiesel production from MOO.	Sulphated tin oxide (3%) was prepared and used for this process. Reaction conditions were varied to generate optimum condition. Reaction parameters include reaction temperature (60 ℃ to 180 ℃), reaction period (1 h to 3 h) and methanol to oil ratio (1:6 to 1:24).	It was observed that the yield up to 84 wt.% of MOB can be obtained with reaction conditions of 150 ℃ temperature, 150 min reaction time and 1:19.5 methanol to oil ratio.	
[30]	Pakistan	Optimization of transesterification process for MOB production using response surface methodology.	Transesterification was carried out with the following varied reaction parameters: 3:1 to 12:1 (methanol:oil) ratio, 0.25% to 1.25% of KOH catalyst, reaction time (20 to 90 min) and reaction temperature (25–65 ℃).	The fuel properties of the MOB produced fulfilled both the ASTM D 6751 and EN 1424 standards. The work demonstrated the usefulness of RSM for optimum conversion of MO to biodiesel.	_

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Reference	Country	Specific objective	Mob production	Findings	Engine performance
[31]	Thailand	Biodiesel from MOO Using K‐Promoted MgAlLa layered double hydroxide (LDH).	The reaction was carried out at 110 ℃ for 6 h with 3:1 methanol: oil molar ratio and 10% catalyst.	The MOB yield was between 95 and 96% after 3 replications and the catalytic leaching was negligible.	
[1]	Malaysia	Investigate the potential production of biodiesel from MO seeds oil using heterogeneous acid and alkali catalyst.	CaO catalyst (1%) was used for transesterification method while $FeSO_4$ (1%) was used for the esterification method. 3 molar ratios were used (6:1, 12:1 and 18:1) for the two reactions at 70 ℃ for a period of 90 min.	The transesterification reaction yielded 96% biodiesel while esterification method yielded 90% biodiesel. Thus MOO is a potential source of biodiesel.	
[32]	Malaysia	Characterization of the physico-chemical properties of MOB and its 10% and 20% by-volume and investigation of engine performance and emission products.	H_2SO_4 and KOH (1% each) catalysts were used. Esterification reaction was carried out for 3 h using 12:1 (Methanol: oil) molar ratio while transesterification method was carried for 2 h using 6:1 (Methanol: oil) molar ratio	The properties of MOB and its blends (10% and 20%) conform to ASTM D6751 standards. Blends of MOB resulted in reduction of BP and BSFC was slightly higher than that of diesel fuel. There was also reduction in CO emission but NO emission was slightly increased when compared with diesel fuel.	Engine performed better with MOB blends than diesel fuel.
[33]	Malaysia	Performance and emission analysis of MOB fuel blends (10% of MOB) in a multi-cylinder diesel engine.	Moringa oil was preheated to 60 ℃, 12:1 molar ratio of methanol to crude oil and 1% H_2SO_4 were added to the preheated oil. For transesterification, 6:1 molar ratio of methanol to oil and 1% of KOH were mixed with the esterified oil. The methyl ester was separated.	Moringa biodiesel and its blends met the ASTM D6751 and EN 14214 standards. BF increased steadily with engine speed using B10 blend. BSFC values were higher for MOB blends than diesel fuel. The blends reduced CO and HC emissions but NO and CO_2 emissions were slightly increased.	

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Reference	Country	Specific objective	Mob production	Findings	Engine performance
[34]	Nigeria	Determination of MO oilseed as a viable feedstock for biodiesel production in Northern Nigeria.	Alkaline catalyzed transesterification reaction was used with a molar ratio of 6:1 (methanol:oil) for 1 h at 60 ℃ using 5% NaOH.	Moringa was discovered to be a feasible source of biodiesel production	
[35]	Brazil	Production of stable biodiesel from MOO and the use antioxidant additives to increase oxidative stability of biodiesel.	Esterification reaction process was carried out by mixing 10:1 ratio of Methanol to oil and 1% H_2SO_4 for 1hr. Transesterification reaction was performed with 6:1 (alcohol/MOO) molar ratio in the presence of 1% KOH catalyst for 1hr at room temperature.	Biodiesel from MOO has a high oxidation stability. Antioxidant additives from ethanolic extracts of MO leaves increased the oxidation stability of biodiesels.	
[36]	Australia	Determination of the Physico-Chemical Properties of MOB blends of 10% to 90% by volume with diesel fuel.	Esterification reaction was carried for 3 h using 12:1 (Methanol: oil) molar ratio with 1% H_2SO_4 while transesterification method was carried for 2 h using 6:1 (Methanol: oil) molar ratio with 1% KOH.	It was found that the fuel properties such as Density, KV, CV, CP, PP, CFPP and FP increases with blending ratio and CV decreases with blending ratio.	_
[37]	Malaysia	Biodiesel production from MO seeds oil using MgO as a catalyst.	Transesterification reaction involved the use of three ratios of methanol: oil (8:1, 10:1 and 12:1) with MgO at 60–70 ℃.	Moringa is an acceptable feedstock for biodiesel production	
[38]	Malaysia	Industrial production of MOB at low cost using KF loaded on CaO and eggshell.	Transesterification reaction was carried out for 1–3 hrs at 50–60 ℃ with molar ratio ranging from 4:1 to 6:1 (methanol:oil) and 1% KF/eggshell with CaO as catalyst.	The work demonstrated that the KF/eggshell catalyst is simple to prepare, economical and satisfactory for biodiesel production.	
[39]	Brazil	Potential application of MOO for biodiesel production.	NaOH and H_2SO_4 catalysts were used. The molar ratio of alcohol: oil: catalyst used was 6:1:0.2	The study revealed that NaOH produced a higher yield of MOB than H_2SO_4. It was concluded that MOB can be used in diesel engines as blends with diesel fuel.	

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Reference	Country	Specific objective	Mob production	Findings	Engine performance
[40]	Brazil	To identify the promising features of MOB for the production of energetic biomass (biodiesel and briquettes).	The transesterification process was carried out under these conditions: 6:1 molar ratio (methanol:oil), 60 ℃, 60 min, 0.8% KOH and agitation of the reaction medium at 300 rpm. Afterwards, the MOME was recovered.	Biomass of MO is favorable for the production of MOB.	–
[41]	Malaysia	To examine the effect of two aromatic amine antioxidants (DPPD and NPPD) on the oxidation stability, engine emission and performance of MOB in a multi cylinder diesel engine.	Catalysts used were H_2SO_4 and KOH (1% each). Esterification reaction was carried for 3 h using 12:1 (Methanol: oil) molar ratio at 60 ℃ while transesterification method was carried for 2 h using 6:1 (Methanol: oil) molar ratio at 60 ℃.	Blends (MB20) treated with DPPD and NPPD emitted lesser amount of NO and higher amount of HC and smoke compared to untreated blends although still below.	Antioxidants improves engine performance.
[42]	India	Production of biodiesel from MOO through transesterification process and evaluation of the performance and emission characteristics of its biodiesel blends with diesel.	Transesterification reaction of 6:1 (methanol:oil) for 2h at 60 ℃ with 1% NaOH catalyst was carried out.	The blends performance of MOB can be compared to diesel fuel and impressive up to B20.	MOB blends improved engine performance with an increase in brake power, rake specific fuel consumption and a decrease in brake thermal efficiency.
[43]	India	Potential of Calcined conch shells (CCSs) as a suitable heterogeneous basic catalyst for transesterification of high FFA content non‑edible *Moringa oleifera* oil (MOO).	H_2SO_4 and CCSs (1.5:8.02%) catalysts were used. Esterification reaction was carried out for 2h using 1:2 (Methanol:oil) ratio while transesterification reaction was carried for 130 min using 8.66:1 methanol to oil molar ratio.	The process was successful and yielded 97.06% of MOB which is within the agreeable range.	-

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Reference	Country	Specific objective	Mob production	Findings	Engine performance
[26]	Iran	Optimization of biodiesel production from *Moringa oleifera* seeds oil in the presence of nano‐MgO using Taguchi method.	Transesterification reaction of 12:1 (methanol:oil) for 4h at 45 ℃ with 1% nano-MgO catalyst was carried out.	It was discovered that the preferred biodiesel bend proportion for optimal performance is 75% and 100% volume ratio.	-
[15]	Iran	Biodiesel production from chicken fat using Nano-Calcium oxide catalyst.	Transesterification reaction was carried out under the following conditions; 1:9 (methanol:oil) molar ratio with 1% CaO nanocatalyst at a temperature of 65 ℃ for 5 hrs.	It was also concluded that biodiesel should not be used in cold weather because its pour point is greater than 0.	-

NPPD: N-phenyl-1,4-phenylenediamine; DPPD: N, N′-diphenyl-1, 4-phenylenediamine; MgO: Magnesium Oxide; MO: *Moringa oleifera*; MOB: *Moringa oleifera* Biodiesel; MOO: *Moringa oleifera* Oil; MOME: *Moringa oleifera* Methyl Esters; H_2SO_4: Sulphuric acid; KOH: Potassium Hydroxide; NaOH: Sodium Hydroxide; $FeSO_4$; CaO: Calcium Oxide; ASTM: American Society for Testing and Materials; EN: European standards; CO: Carbon monoxide; CO_2: Carbon dioxide; NO: Nitrogen Oxide; HC: Hydrocarbons; BP: Brake Power; BFSC: brake specific fuel consumption; RSM: Response surface Methodology; KF: Potassium Fluoride; CV: Calorific value, CP: Cloud Point, PP: Pour point; FP: Flash point; B10: 10% biodiesel + 90% diesel; B20: 20% biodiesel + 80% diesel.

4. Discussion

Biodiesel as an alternative energy source is gradually gaining acceptance [44]. The use of plant as a form of biodiesel is fast increasing. *M. oleifera* oil which is extracted from *M. oleifera* plant is categorized among the non-edible oil and now listed among the feedstock for biodiesel production. Considering certain characteristics *M. oleifera* oil possess which is similar to conventional diesel, *M. oleifera* oil offers a cleaner and better alternative [18]. This review reports the properties, storage and oxidative stability and performance in combustion engine of *Moringa oleifera* biodiesel (MOB).

4.1. Oil extraction from seeds and percentage yield

Several methods have been established for the extraction of oil from seeds. The existing methods for extracting oil from *Moringa oleifera* seed includes mechanical extraction method, solvent Soxhlet extraction method using n-hexane and ethanol [45–47,25,26] and supercritical extraction with CO_2 [46,48,49]. Although, extraction using supercritical fluids is gaining increasing attention over Soxhlet extraction method because it produces clean oil and the process is sustainable, the latter is still very much in use. Before the oil extraction process, Moringa kernels are properly cleaned to remove debris and further cracked open to obtain the seeds. The seeds can be sun dried or oven dried, and then milled to flour in an attrition mill to obtain a smooth Moringa flour. Soxhlet extractor is then utilized to extract oil from the flour using n-hexane as solvent. The boiling point of hexane is lower than that of the oil, thus hexane evaporates first leaving the oil in the soxhlet extraction flask. The oil obtained (crude oil) is allowed to dry in an oven at 105 ℃ for roughly 2 hours and cooled in desiccators before further use [25]. The yield of the oil obtained varies depending on the type of extraction method used and the overall reaction conditions. Ahaotu et al. [25] recorded 38% oil yield using the soxhlet extraction method with n-hexane as solvent. However, Dom ńgueza et al. [47] carried out extraction analysis from Moringa seed making use of different solvents such as hexane, ethanol and petroleum ether. The results indicated that the percentage oil yield was higher when hexane and petroleum ether were used as solvent. Although this result negates the report of Palafox [49], that ethanol is a better solvent than hexane, petroleum ether and acetone. Nguyen et al. [46] extracted oil from Moringa kernels using supercritical fluid method and recorded an oil yield of 37.84%. According to Abdulkarim et al. [50], some enzymes can be used to enhance the recovery of oil from seed. This is also confirmed by Ofor and Nwufo, [27]; Nadeem and Imran [24] and Zeeshan et al. [42]. The enzymes include Neutrase, Termamyl, Celluclast and Pectinex. These enzymes can be used separately or combined. However, high oil recovery (74%) is obtained when the enzymes are combined [50].

The physical and chemical properties of MOO are given in Table 2. MOO is light yellow in color and has a characteristic pleasant nutty flavor. The free fatty acid content fluctuates between 0.5 and 3% [25]. The high Iodine value of MOO indicates that biodiesel from Moringa oil will have an improved stability over conventional diesel fuel [24]. The fatty acid composition of MOO makes it suitable for both edible and non-edible applications [27,42].

Table 2. Physicochemical properties of Moringa oleifera seed oil [51].

CHARACTERISITICS	*Moringa oleifera* oil (MOO)
Percentage of oil Yield	45%
Acid value (mg KOH/g)	4.91
Free fatty acid Value (mg KOH/g)	2.45
Saponification Value (mg KOH/g)	164
Density (gcm 2)	8.44
Specific gravity (400C)	875
Iodine Value (gI2/100 g of oil)	85.55
Peroxide Value	3.50
Refractive index at 400C	5.21
Viscosity at 400C mm2/s	4.3

The fatty acid compositions of Moringa oil are given in Table 3. *Moringa oleifera* oil, commonly called Ben oil, consists of roughly 13% saturated fatty acids and 82% unsaturated fatty acids. Oleic acid is the major component of Ben oil and it has a lot of health benefits such as preventing ulcer, reducing blood pressure and increasing fat burning. The oleic acid content of Ben oil (67.3%) is high when compared with other vegetable oils which contain about 40% oleic acid [50,47,25]. Oleic acid from Ben oil has been reported to have good oxidative stability which makes it useful in the food industry, medicine and water treatment. The oil also has the ability to absorb and retain volatile substances, thus it is highly required in the perfume industry for stabilizing scents [25]. Palmitic acid is a 16C saturated long chain fatty acid which is abundant in plants like palm oil, palm kernel oil, Ben oil, in animals and animal products like cheese milk and meat. Icosanoic acid (Arachidic acid) is a 20C saturated fatty acid found naturally in minute quantity in Peanut oil and also in Moringa oil. It has found applications in the industry as component of adhesive, sealant and lubricants. Another important fatty acid found in ben oil is stearic acid, an 18C saturated fatty acid. It is relevant in the production of detergent, soaps and cosmetics. Soap is indirectly made from stearic acid by saponification of triglycerides of stearic acid esters. Myristic acid is naturally found in palm oil, coconut oil and butter fat and it is used as a flavoring agent in food. Another major component of Ben oil is Behenic acid (from which the name 'Ben' is derived) commonly used to give hair conditioners and moisturizers their smoothing texture [25,52,53].

Table 3. Fatty acid compositions of Moringa oleifera seed oil [25].

Fatty acids	Chemical formula	Mole Fraction (%)
Behenic acid (C22:0)	$C_{22}H_{44}O_2$	4.1
Myristic acid (C14:0)	$C_{14}H_{28}O_2$	0.5
Erucic acid (C22:1)	$C_{22}H_{42}O_2$	1.7
Oleic acid (C18)	$C_{18}H_{34}O_2$	67.3
Arachidic acid (C20)	$C_{20}H_{40}O_2$	5.5
Linolenic acid (C18:3)	$C_{18}H_{30}O_2$	1.1
Stearic acid (C:18)	$C_{18}H_{36}O_2$	4.5
Palmitoleic acid (C16:1)	$C_{16}H_{30}O_2$	2.5
Palmitic acid (C16)	$C_{16}H_{32}O_2$	7.9

4.2. MOB techniques

It can be produced by various technologies such as homogeneous catalytic transesterification (acidic, basic or mixed), heterogeneous catalytic transesterification (acidic, basic or with natural resources), enzymatic transesterification, ultrasonic and microwave assisted transesterification, supercritical and membrane technologies and by reactive distillation.

Several techniques have been established for biodiesel production, like pyrolysis, the supercritical fluid method, transesterification, micro-emulsion, and catalytic distillation. However, the technique frequently used among these is transesterification [54]. Most literature illustrates the production of MOB using the transesterification method (Table 2). Transesterification is the reaction of a fat or oil with an alcohol to form esters and glycerol in the presence of a catalyst. The alcohol frequently used is methanol and ethanol, though, ethanol is the preferred alcohol since it is renewable and derived from agricultural products. However, methanol is mainly employed because of its low cost and its physical and chemical advantages [55]. The catalyst used can be homogeneous, heterogeneous or enzyme catalyst [54,56]. Homogenous catalyst are extensively utilized in industrial processes because of its high yield, fast reaction rate and minimal reaction condition requirements. However, the process is expensive and time consuming [43]. The homogeneous catalyst includes acid and base catalysts. The most frequently used base catalysts are NaOH, KOH and CH_3ONa while H_2SO_4 is the most utilized acid catalyst among others like HCl, H_3PO_4 and BF_3 [57]. In most of the studies, the preparation method was catalyzed by Potassium hydroxide which according to Karmakar et al. [58] gives better yield than sodium based catalysts. Although base catalyzed processes are fast, it is affected by free fatty acids present in fats and oil. The free fatty acids may react with the base catalyst to form soap and water which makes recovery of biodiesel difficult, thus reducing biodiesel yield and production cost increases. In contrast to this, acid catalyzed processes are slow and requires large amounts of alcohol. Another type of catalyst used is the heterogeneous catalyst which involves a combination of acid and base catalyst. This type is preferred due to ease in separation of the final product and the catalyst can be reused. An emerging catalyst type is the nano-catalyst which is gaining attention because of its high catalytic efficiency, large surface area and enhanced activity and stability [54]. Thus adopting a two-step transesterification technique could provide large biodiesel conversion of up to 98% [59]. Furthermore, enzymatic transesterification method is more valuable in terms of conversion of oil to biodiesel, biodiesel yield and reusability of the enzyme but chemical catalyzed transesterification reactions has prevailed in the past. The use of Lipase improved the rate of reaction and conversion. Another method has been introduced which makes use of immobilized lipase [19].

Another method of producing biodiesel is the use of supercritical fluid which does not require catalysts. Supercritical fluids are substances at temperature and pressure above their critical points. They diffuse through solids like a gas, and dissolve like a liquid. Water, Carbon dioxide and alcohol (methanol or ethanol) are normally used as supercritical fluids. The important factors affecting this process includes temperature, pressure and molar ratio between the alcohol and oil. High temperature, pressure and molar ratio between the alcohol and oil favors transesterification method using supercritical fluids. The supercritical process is more efficient, has a short reaction time and the products are easily purified. However, the limitation in this process is energy consumption and the use of excess alcohol. Microwave assisted process is another efficient transesterification method that reduces the quantity of by-products and separation time, but increases the quality and yield of the biodiesel. The disadvantages of this method includes difficulty in scaling up to industrial production and the dangers associated with the use of industrial microwave reactors. Ultrasound assisted process makes use of sound waves [57].

The product of the transesterification process includes the alkyl ester product and also the residual alcohol and catalyst. The by-product glycerol is separated from biodiesel although traces of it can be found in the final biodiesel product [14]. MOB is easy to recover and its quality is higher than other crops [24,58].

4.3. Current trend of heterogeneous catalyst utilization

Heterogeneous catalysts allows for simultaneous esterification and transesterification reactions. This category of catalysts are more affordable than homogenous catalysts, and can easily be separated from the biodiesel and recycled [26,60]. The current trend in the production of biodiesel (using heterogeneous catalysts) involves impregnation and functionalization of catalysts. The two main impregnation approaches are wet impregnation (an excess amount of solution is introduced) and dry impregnation (the impregnated material is kept dry at a macroscopic scale). The functionalization of the catalysts (such as CaO, MgO, SiO_2–Pr–SO_3H, mesoporous SBA-15) promotes stable and highly efficient catalytic performance, produces low freezing point biodiesel, and enhances high surface area and uniform porosity of the catalysts, as well as excellent water and acid resistant ability [61–63].

Fitriana et al. [64] synthesized K_2O/Zeolite catalysts by KOH impregnation for biodiesel production from waste frying oil, high biodiesel yield of 95% was produced from the reaction with 2.1 wt.% catalyst of 25% KOH impregnated.

A recent trend is the application of nano-sized heterogeneous catalysts in biodiesel production. Nanocatalysts have a high specific surface area than the commonly utilized catalysts which is required for efficient transesterification process [26,65]. Some researchers have reported on biodiesel production using nanocatalysts. Mohadesi et al. [66] studied biodiesel production from sunflower oil using alkali metal oxides likes MgO/SiO_2, CaO/SiO_2, and BaO/SiO_2. Also, Bet-Moushoul et al. [67] produced biodiesel from sunflower oil by the use of CaO/Au heterogeneous nanocatalyst.

4.4. Physico-chemical properties of MOB

The physico-chemical properties of MOB are given in Table 4. Literature reveals that the physical and chemical properties of MOB meet the ASTM D6751 and EN 14214 standards, although the values from different studies may vary due to differences in production techniques and reaction conditions [12,68].

Table 4. Physico-chemical properties of *Moringa oleifera* biodiesel compared with Conventional diesel and International standards.

Some properties	MOB	Conventional Diesel	ASTMD 6751	EN 1421	References
Flash point	162	60–80	130 min	120 min	21, 69, 70
Pour point (℃)	17	−35 to −15		-	21, 69
Cloud point (℃)	18	−15 to 5		-	69
Viscosity at 40 ℃	4.80	2.0 to 4.5	1.9–6.0	3.5–5.0	21, 69, 70
Calorific value (MJ/kg)	42	44.8	42–45	42–45	70
Density (Kg/m^3)	875	820–860	-	860–900	21, 69
Free fatty acids	6.678	-	-	-	70
Cetane number	67	46	47 min	51 min	21, 69
Carbon residue (wt%)	0.050	-	0.050	0.050	70
Acid value (mg KOH/g)	0.38	-	0.50	0.50	69, 70

Several studies agreed that the cetane number of the MOB (approximately 67) is higher than other biodiesel [17,18,69]. The cetane number is linked with the ignition quality of the fuel. Cetane number increases with the number of carbons in the chains but decreases with the number and location of double bonds [18]. MOB has C18 in its chains which may contribute to its high cetane number. MOB exhibits a brilliant lubricity [17]. The viscosity of MOB is higher than that of diesel fuels. The viscosity of fuels affects its injection process and fuel spray into the combustion chamber. Viscosity varies with temperature, the lower the temperature, the higher the viscosity [12]. MOB flash point is within the acceptable standard range and it is higher than what is obtained in diesel fuels. Flash point is associated with safety during fuel storage and transport. Thus, the high flash point of MOB makes it safe during storage and transport [26]. The free fatty acid content of the oil used will determine the quantity of biodiesel produced. Low free fatty acid content (below 0.2) can result in high biodiesel yield, close to 100%. The calorific value of MOB is within the range of accepted international standards.

4.5. Storage stability/oxidative stability

A major challenge of diesel and biodiesel fuel is oxidative stability which is a measured by ASTM D2274. Biodiesel fuels are more sustainable to oxidation. Karmakar et al. [58] reported enhanced oxidative stability in the MOB. The degree of saturation is likely associated with its stability. Methyl esters are slightly more stable than ethyl esters. Temperature and the type of storage vessels influence storage stability [18]. Our studies provided little information on the oxidative stability and storage stability of *M. oleifera* biodiesel (Table 2).

4.6. Engine performance and emissions

MOB can be used directly to fuel diesel engines or may be blended with diesel fuel at different proportions from Zero (B0) to as much as 100% (B100). When blending biodiesel with diesel, the diesel should be added first before the biodiesel else it will not mix [71]. The parameters associated with engine performance include brake power, brake thermal efficiency and brake specific fuel consumption [42]. When compared to diesel fuel, MOB exhibit lower brake power and slightly higher brake thermal efficiency (BTE) due to its low heating value, and high viscosity and density. High viscosities result in delayed engine starting and poor performance. Several methods to reduce the viscosity of vegetable oils have been identified, some of which include dilution, catalytic cracking and transesterification. Of these 3 methods, transesterification is a well-known and excellent method of reducing vegetable oil viscosity and converting the large, branched molecules of the oils into smaller, straight-chain molecules which is the desired type in regular diesel engines [12].

Similarly, with respect to engine emissions, MOB blends were reported to reduce Hydrocarbon, Carbon monoxide and Particulate matter emissions. However, Nitrogen oxides and Carbon dioxide emissions were increased compared to diesel fuel. This indicates that the performance of MOB blends at 5% and 10% is impressive and can be used in combustion engine which will reduce dependence on fossil fuels and eventually lessen the release of exhaust emissions [72].

4.7. Challenges

Biodiesels are susceptible to degradation due to fatty acid chain unsaturation. Biodiesel degradation is intense in the presence of two or more bonds in the fatty chain. Nevertheless, the degradation process of biodiesel can be drastically reduced by adding antioxidants [41]. Some challenges encountered by carbon deposits on piston, piston rings, valves, engine head and injector tips, filter plugging, injector coking, nozzle blocking, failure of engine lubricating oil, heavy gum and wax formation [73].

5. Conclusions

This review has highlighted the many possibilities of *Moringa oleifera* oil as a feedstock for biodiesel production. Extraction of oil from Moringa seed and its conversion to biodiesel using various methods were discussed in this review alongside the physicochemical properties of the crude oil and biodiesel. The global interest in the use of *Moringa oleifera* seed oil for biodiesel production is increasing daily since the plant is readily available, economical, biodegradable, and resilient to harsh environmental conditions. Several methods have been established to extract oil from Moringa seed with an appreciable average yield of about 40% which can be improved to about 70% yield with the application of enzyme technology. The fatty acid composition of Moringa oil demonstrates a high oleic acid content and it is very stable compared to conventional diesel. Biodiesel production from Moringa oil can be carried out using transesterification method, supercritical fluid method, microwave and ultrasound-assisted method. All literatures reviewed recorded that the physicochemical properties of Moringa biodiesel meets EN 14214 and ASTM D6751 international standards. A distinct property is the cetane number of Moringa biodiesel (67) which is the maximal number documented for biodiesel. *M. oleifera* biodiesel has great potential in contributing to the reduction of greenhouse gases and ensuring sustainable supply of energy. As the search for cleaner and sustainable source of energy continues, tapping into this green field would be worth investigating.

Acknowledgements

This research was funded by Covenant University Centre for Research Innovation and Discovery, grant number VC/CRD.05/CUCRID RG 016.12.14/FS and the APC was funded by Covenant University Centre for Research Innovation and Discovery.

Conflict of interest

The authors declare no conflict of interest.

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